Satellite Dynamics About Asteroids

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Current goals for planned and proposed missions (NEAR, MASTER) call for a period of orbital operations about an asteroid. A challenge for the navigators of these satellites is to predict the orbital environment about these asteroids and to derive pre-mission plans for the control of these orbits. This paper investigates the major perturbations asteroid orbiters will encounter over a range of asteroid sires, and describes the generic motions the satellite orbits will follow.

The relevant perturbations acting on the satellite at the asteroid will be due to the irregular shape of the body, solar radiation pressure and solar tide. Each one of these perturbations will have different effects on the satellite' motion. In some cases, orbits may be designed whit.1 effectively balance the forces, enabling a frozen orbit design. To properly discuss these orbits, the averaged Lagrange Planetary equations are derived for each of the major perturbations. It is seen that these averaged equations provide accurate qualitative prediction of the expected satellite motion. Exact solution of these averaged equations are possible when either the shape or solar radiation pressure alone are present. When both are modeled, only particular solutions may be found.

In addition to these specific predictions of motion, it is possible to characterize the dynamical environment about asteroids according to their shape. From this characterization, one may infer regions of orbital stability and instability about the body. Also, certain rule-of-thumb formulae may be derived which provide worst case analyses of orbital scenarios about asteroids with poorly known shape or size. This shape characterization assumes the asteroid may be modeled as a constant density tri-axial ellipsoid, a reasonable estimate for an asteroid shape in the absence of dime.t observation.

The study carried out in this paper is significant as it addresses the non-Keplerian nature of satellite orbits about asteroids. For any potential orbiter mission to an asteroid, these effects must be seriously considered during pre-flight navigation and mission planning. This paper provides an analysis and methodology which allows for qualitatively correct pre-flight planning.

Following are a series of plots which graphically show the range of dynamical effects possible when orbiting asteroids of various sizes and types. Figure 1 depicts an orbit about an asteroid modeled as a tri-axial ellipsoid witl I semi-major axes of 20 X 7 X 7 km and a density of 3.5 g/cc. The asteroid rotates about its largest moment of inertia with a period of 5.27 110111"s. The orbit starts with an initial radius of 40 km (a one radii altitude) and local circular velocity. Figure 1 depicts the evolution of the orbit over 5.4 days, at which point the orbit crashes into the asteroid. This plot is in a inertial reference frame. The possible existence of such dynamics over a short time span motivates the need for a deeper understanding of this problem.

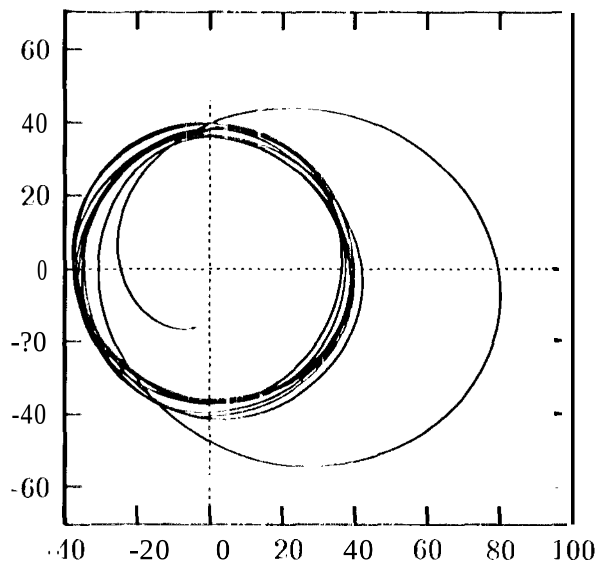

Figure 1: Initially circular orbit to crashing orbit in < 6 days

For asteroids modeled as tri-axial ellipsoids it is possible to identify those asteroids where such crashing orbits are likely. This determination is a function of the asteroid shape, size, density and spin rate. The analysis also indicates how such orbits can be avoided.

Figures 2 and 3 depict orbits shout a small, near Earth asteroid, where solar pressure effects broom e 1 arge. The asteroid in this case is assumed spherical with a radius of 0.4 km and a density of 3.5 g/cc. The plots are in an asteroid cer itered frame rotating with the asteroid about the sun. The orbits in these plots start at a 5 km radius, or at an altitude of greater than 11 asteroid radii. At these distances the effects of the asteroid shape 011 the satellite trajectories are small dative to the solar p ressure effects.

The orbit in Figure 2 is in the asteroid orbital plane and shows a 1() day evolution of the initially circular orbit,. Note the rapid change in the orbit, due to the solar radiation pressure forcing the eccentricity towards unity. The semi-major axis of the orbit remains constant 011 average. Both of these effects can be explicitly predi cted in terms of averaged orbital elements. Using these, the time to crash onto a finite radius asteroid for this type of orbit may be predicted.

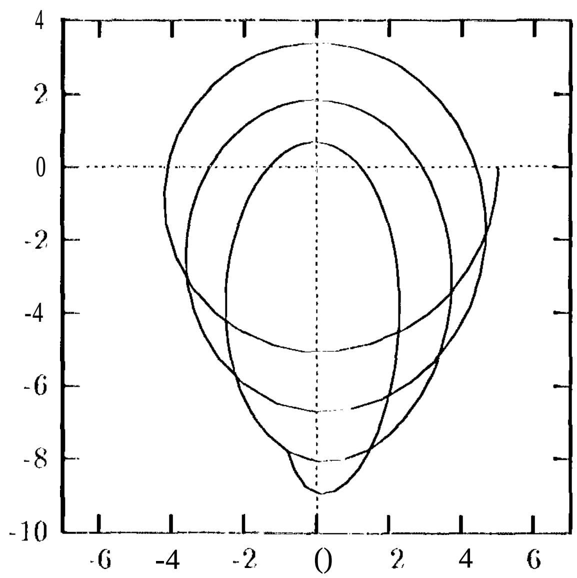

Figure 2: Circular Orbit in Asteroid orbital Plane

The orbit in Figure 3 is in the sun plane-of-sky (an orbit which faces the sun, centered at the asteroid). In this case, the orbit is propagated 100 days as the asteroid follows an assumed circular path about the sun. The orbit tends to stay in the sun plane-d-sky, and thus the solar radiation pressure forces the mbit to follow the sun. This result may be explicitly predicted from the analysis. It raises interesting possibilities for rosily navigated orbits and mission design.

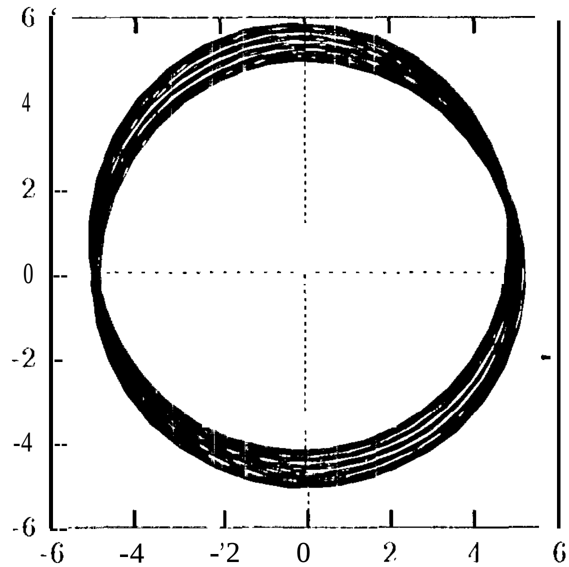

Figure 3: Circular Orbit in Sun Plane of Sky

Finally, Figure 4 depicts the longitude of the ascending node of a satellite's orbit about an asteroid, modeled as a tri-axial ellipsoid with smlli-axes 265 x 25(I x 220 km. The orbit is nominally circulai with a radius of 500 km and has a 45° inclination with respect to the asteroid rotation pole. Note the large rate of nodal regression, over 30° per day. This nodal regression rate may also be predicted using the averaged orbital elem ents. '1 'II eexistence of nodal rates of this size is a serious matter and should be factored into any navigation and mission pla ns.

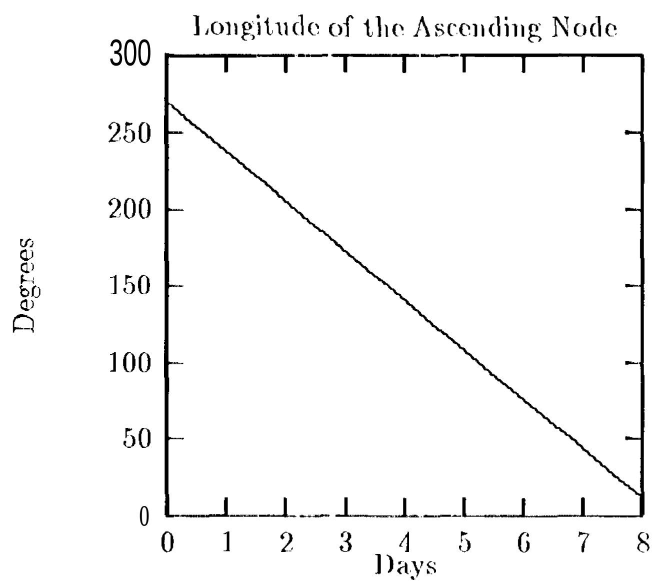

Figure 4: Satellite Orbit Node About Large Asteroid

In all the above plots, it is possible to give accurate analytical prediction of these motions. The equations and methods used to do so are described and derived in the paper. Due to the relatively large perturbations which act 011 the satellites in the asteroid environment, the resulting motion is significantly non-Keplerian. Thus, traditional intuition may not apply when designing navigation strategies about asteroids. The aim of this paper is to provide a number of results and analyses which will allow realistic pre-mission planning for asteroid orbiter missions.